SANDY BARRIER CHANGES AT THE NINETY MILE BEACH, LAKES ENTRANCE, VICTORIA, AUSTRALIA

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ABSTRACT

Coastal monitoring with high resolution is necessary to provide coastal managers with the optimal data and information for decision-support, especially across sandy terrain, such as beaches and dune systems. Dynamic sandy barrier coastlines pose particular problems in this regard, as a range of physiographic processes and anthropogenic influences can interact to rapidly alter the morphology of these locations. At Lakes Entrance (Victoria, Australia), survey charts and high resolution aerial orthophotos of the Ninety Mile Beach to the west and east of the Gippsland Lakes artificial entrance have been analysed using GIS to show time-series sandy terrain and stabilising vegetation changes between 2005-2009. Information has also been analysed with particular regard to documenting sandy barrier shoreline changes between 1892-2009. This information is valuable as a means of monitoring sandy barrier 'sediment compartment' changes during future sediment management operations at the ebb- and flood-tide deltas at the Gippsland Lakes entrance. During future sediment bypass operations associated with the $AU 31.5 million Lakes Entrance Sand Management Program (LESMP, 2006), further high-resolution monitoring of this kind should be applied to routinely monitor for sandy barrier changes.

INTRODUCTION

The maintenance of sandy barriers formations are of great significance to coastal managers, especially those concerned with the management of modified or artificial entrance openings to coastal lagoons or tidal inlets. Frequently, these entrances are required to support port infrastructure located in back-barrier areas, and are often maintained via dredging and/or training walls (e.g. see Wheeler and Peterson, 2005; Wheeler *et al*., 2009; Bird and Lennon, 1989). Artificial entrances, channel maintenance dredging and coastal armouring structures can influence sediment budgets (van Rijn, 2004) such that engineered sediment bypass operations are required to be commissioned in order to ensure a continual supply of sediment for maintenance of down-drift barrier shorelines (e.g. see Lawson *et al*., 2001; Cheung *et al*., 2007). Present at these dynamically changeable locations are a series of interconnected morphological units (refer figure 1); a tidal entrance which divides ebb- and flood-tide deltas, up-drift and down-drift nearshore littoral zones, and sandy barriers (which are located above high

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water mark) (e.g. see Hayes, 1980). Sands are continually exchanged between these 'sediment compartments'. Littoral (or longshore) drift direction along the coast in the nearshore zone may alternate, dependant upon wave direction. Heavy and/or sustained down-drift shoreline erosion can occur, as nourishing sediment from the up-drift littoral zone is lost to the down-drift sediment budget via deposition at the flood- and ebb-tide delta morphological units. Should sediment bypassing around an entrance be neglected, or not sized correctly, extensive sandy barrier accretion up-drift, and heavy erosion down-drift can result (Bruun and Willekes, 1992).

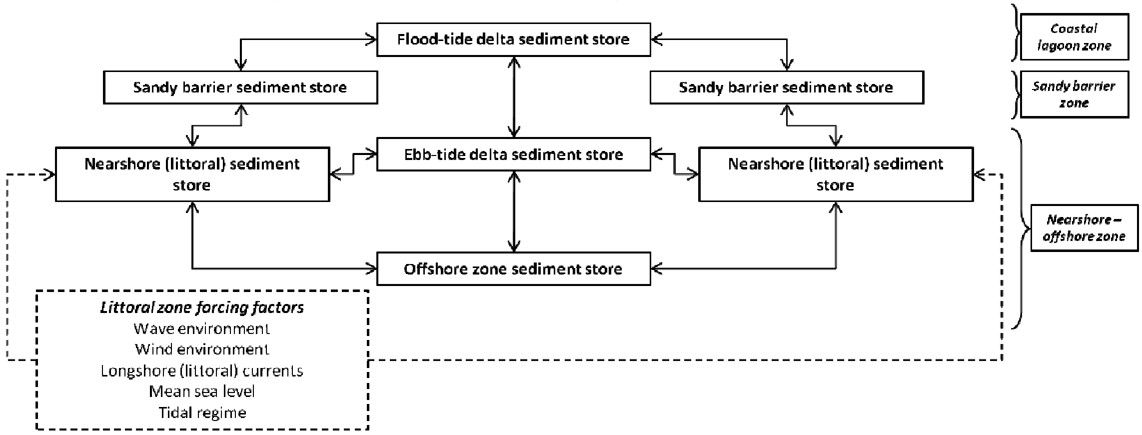

Figure 1. Interconnected morphological units at a coastal lagoon/tidal inlet entrance.
Source: after Wheeler *et al.*, (2009).

The terrestrial components of the sandy barrier 'compartment' include not only the beach berm, but also the foredune and the older sand beach ridge complex behind it. Although helpless against recessionary momentum, the viability of exposed dune-binding vegetation associations (*Festuca littoralis*, *Spinifex hirsutis*, and the introduced marram grass *Amophilia arenaria)* together with more established dune-scrub communities (commonly made up of *Leptospermum laevigatum*, *Acacia longifolia*, and the coastal banksia (*Banksia integrifolia*) immediately inland must also be a part of sand compartment monitoring, because exposed sand can blow out into transgressive dune sheets that remove sand from the coastal store, and thus, from its role as a buffer against the worst effects of episodes of recession.

At Lakes Entrance, located in the Gippsland region of Victoria, Australia (refer figure 2), a back-barrier port developed progressively after the 1889 opening of an artificial entrance through a Holocene sandy barrier formation between the Gippsland 'Lakes' (a 400 km^2 coastal lagoon system, with seven major influent streams draining a catchment of 20,000 km^2) and Bass Strait (e.g see Bird and Lennon, 1989). Since entrance opening, inexorable shoaling to seaward and landward of the entrance has taken place to form extensive ebb- and flood-tide deltas, and Ninety Mile Beach sandy barrier shoreline profiles have been significantly altered due to obstruction of littoral drift by the artificial entrance (e.g. see Wheeler and Peterson, 2005; Wheeler *et al.*, 2009; Royal Commission on Victoria's Outer Ports, 1927).

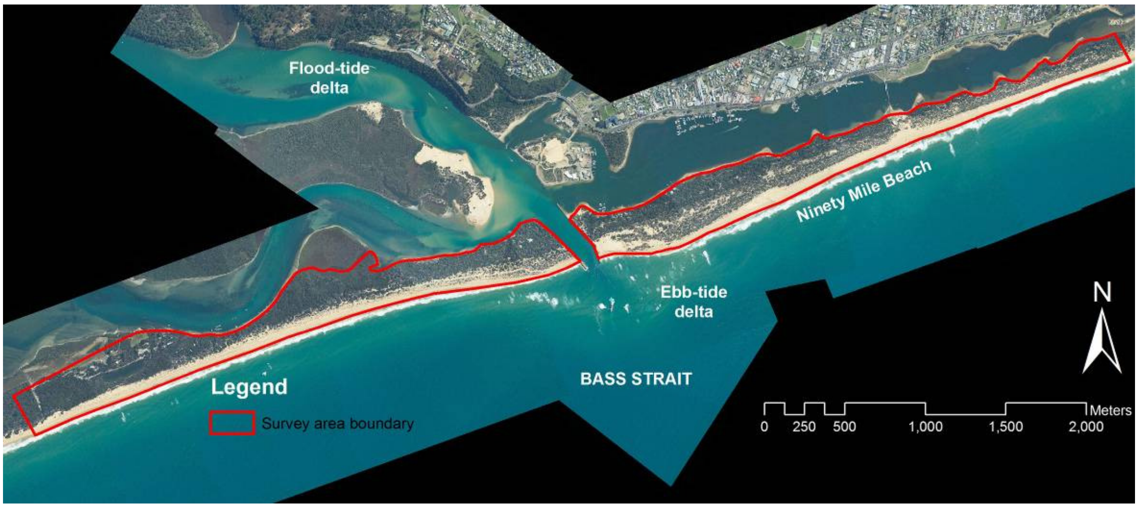

Figure 2. The Gippsland Lakes artificial entrance, Victoria, Australia, showing survey area.

Prerequisite to the formation of prominent coastal sand barriers is an abundant source of barrier building materials, a micro-tidal range, and a dominant swell-wave regime (e.g. see Bird 1967, Thom, 1984). They account for the formation of the barrier that separates the Gippsland Lakes from Bass Strait, to which it presents itself in the form of the Ninety Mile Beach. Formed from approximately 6.5ka, it is a quartz-sand barrier (<10% calcium carbonate) with no underlying aeolianite platform. The exchanges between components of the sand store are thus unconstrained in these terms. In the area in the immediate vicinity of the Gippsland Lakes artificial entrance, the stabilising affects of barrier vegetation types, and the nourishment of down-drift barrier beaches (via natural or artificial means) from the Gippsland Lakes artificial entrance is of utmost importance to sandy barrier stability.

As a necessary pre-requisite to inform future bypass operations at the Gippsland Lakes artificial entrance, as called for by the $AU 31.5 million Gippsland Ports-administered Lakes Entrance Sand Management Program (LESMP, 2006), both an appraisal of historical Ninety Mile Beach sandy barrier shoreline changes in the vicinity of the artificial entrance, and future digitally-based high-resolution monitoring of environmental changes to up- and down-drift sandy barriers and beaches are called for. This GIS-based study uses, as primary datasets, historical survey charts dating from 1892, and more recently acquired high-resolution aerial orthomosaics (captured at regular intervals between 2005 and 2009), to map and quantify Ninety Mile Beach sandy barrier sea-shoreline changes, and stabilising vegetation changes, across the survey area detailed at figure 2. The methodology described in this study can be readily deployed for environmental management tasks relating to the monitoring of any coastal sandy barrier/terrain environment. Results reported here are directly applicable to the future management of the sandy barrier environment in the vicinity of the Gippsland Lakes artificial entrance (especially when related to sediment bypassing operations).

They show the utility of GIS-based analysis for timely coastal zone monitoring, evaluation and reporting.

METHODOLOGY

Survey area sand and vegetation coverage change detection

High-resolution colour orthophoto mosaics (pixel resolution 0.4m) of the survey area were obtained in time-series between December 2005 and March 2009 (refer table 1). A study process-flow diagram is provided at figure 3.

Table 1. Time-series survey area orthophoto capture dates

Orthophoto mosaic capture date
1. 14 December 2005
2. 04 July 2006
3. 12 September 2006
4. 11 December 2006
5. 03 March 2007
6. 04 June 2007
7. 03 March 2008
8. 12 June 2008
9. 01 September 2008
10. 01 December 2008
11. 09 March 2009

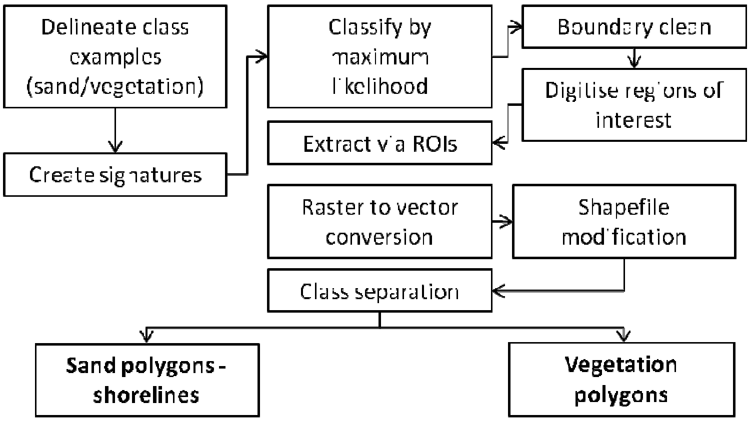

Figure 3. Study process-flow diagram

In order to examine study area sandy barrier time-series shoreline and vegetative cover changes, a process of delineating boundaries between sand and vegetation was carried out. The first step related to creation of a training dataset which comprised two signatures (sand class and vegetation class). Resultant polygon shapefiles were assigned two kinds of attribute values in the Id field (0 = sand and 1 = vegetation). These values were deployed during the classification process to divide sand and vegetation raster layers from raw air photo mosaics. The maximum likelihood classification plays the most important role in the overall methodology. The standard maximum likelihood classifier is one of the most widely used methods of classification in remote sensing. It is a statistical and parameters-based classification that allocates each pixel to the corresponding class based on the highest posterior probability of class membership stated in the following equation (de Jong and van der Meer, 2006):

$$L(i/x_k) = \frac{P_i p(x_k/i)}{\sum_{j=1}^{c} P_j p(x_k/j)}$$

where $L(i/x_k)$ is the posterior probability of pixel with the data vector x_k belonging to class i, P_i the priori probability for class i, and c the total number of classes and $p(x_k/i)$ is the probability density function for the pixel k with the data vector x_k as a member of class i,

$$p(x_k/i) = \frac{1}{\sqrt{2\pi}\sqrt{|M_i|}} \exp\left(-\frac{1}{2}D^2\right)$$

where M_i is the variance – covariance matrix for class i and D^2 is the Mahalanobis distance between the pixel k and the centroid of class i. The Mahalanobis distance is calculated from,

$$D^2 = (x_k - v_i)^T M_i^{-1}(x_k - v_i)$$

where v_i is the mean vector for class i.

The maximum likelihood algorithm is the most accurate classification as it considers both the variances and co-variances of the class signatures when assigning each cell to one of the classes represented in the signature file. The distribution pattern of each category (class) can be described by the mean vector and the covariance matrix. One of the disadvantages of this supervised classifier is that it is computationally demanding. The maximum likelihood approach however is trusted herein among various classification (both supervised and un-supervised) methods (Richards and Jia, 2006) due to its optimality in the sense that, on average, its use yields the lowest probability of misclassification (Ambadon, 2007). After classifying, the refinement tool 'boundary clean' was applied to the raster layers that were obtained in the previous step. The boundary clean function is primarily used for cleaning ragged edges between zones. It uses an 'expand' and 'shrink' method that cleans boundaries on a large scale. This function is employed to improve the smoothness of the boundaries of classes thereby eliminating the constraints upon boundary delineation imposed by 'mixed' pixels. Any abnormalities regarding the classification results, due to noises and/or bad quality of the original images, were dealt with via this cleaning method. Results provide time-series sand and vegetation coverage polygons which can be assessed for coverage visual and area changes with high-resolution (refer figure 4)

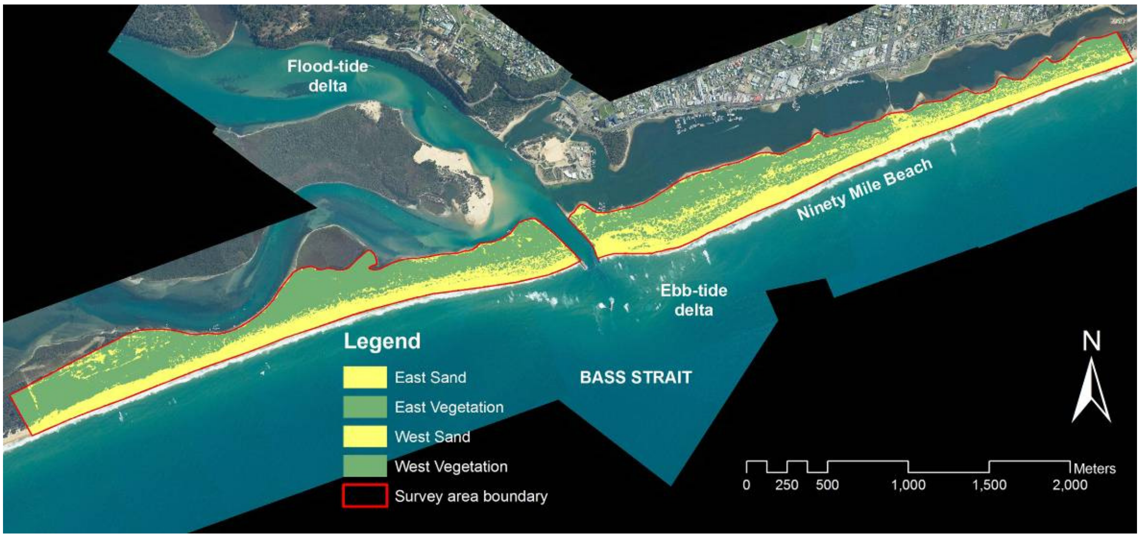

Figure 4. Automatically-derived survey area vegetation and sand polygons for March 2009 imagery.

Survey area shoreline change detection

In order to document time-series shoreline changes via extraction of shorelines from aerial orthomosaic images, shoreline transect casting was performed using Digital Shoreline Analysis System (DSAS) version 3.x ESRI ArcGIS extension (Thieler *et al.*, 2005). This extension is implemented in VB.NET using the ArcObjects Object Library for ArcGIS 9. It was designed to aid in historic shoreline change analysis. DSAS works by generating orthogonal transects at a user-defined separation and then calculates rates of change and associated statistics that are reported in attribute tables (geo-spatial database). This parameter is changeable in the DSAS extension interface. Distance between transects was 100m, and there were 140 transects cast across the survey area shorelines in total (71 east of the artificial entrance, and 69 transects west of the artificial entrance - refer figure 5). To calculate the shoreline rate of change, the traditional statistics End Point Rate (EPR) were used among the many different methods offered by the DSAS tool. Theiler *et al.* (2005) relates that EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements. Major advantages of EPR relate to its ease of computation and minimal requirement for shoreline data. To increase shoreline change time-series results, a survey chart complied in 1892 was georeferenced, and after digitisation, shorelines rate of change at each EPR transect between 1892 and 2009 was manually obtained.

Figure 5. Positioning of east and west transects adjacent to the Gippsland Lakes artificial entrance to monitor sandy barrier shoreline changes.

RESULTS

Survey area vegetation change results are shown at figure 6. These show that there is a seasonal variation in sandy barrier vegetation coverage extent, which peaks in June/July (winter), and is at its lowest extent in December (summer). Conversely, maximum visible sand coverage occurs in summer (December), and minimum visible sand coverage occurs in winter (June/July).

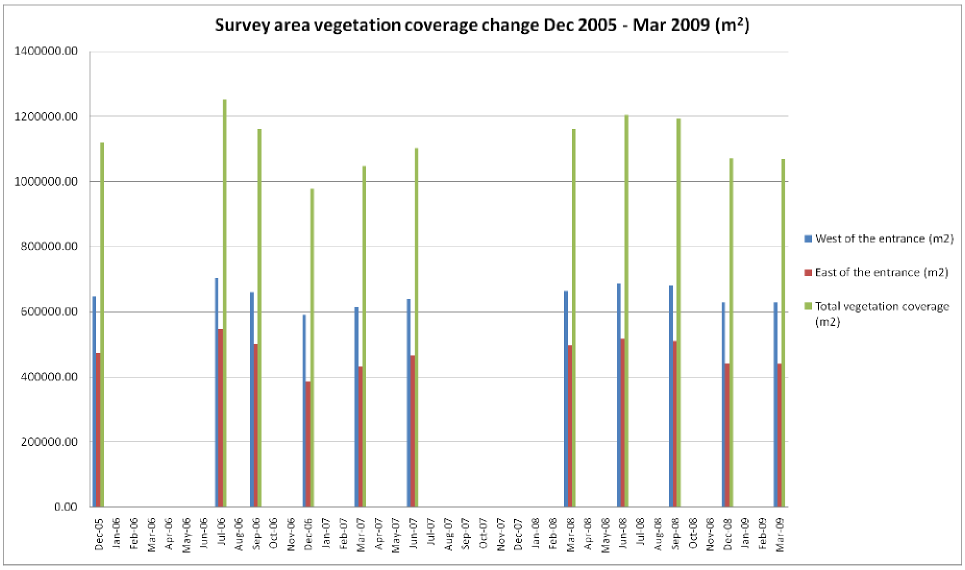

Figure 6. Survey area visible vegetation coverage change for December 2005 to March 2009

Sandy barrier shoreline changes to the east and west of the artificial entrance have been significant in the period 1892-2009. Shoreline progradation has taken place to the east of the entrance, and significant shoreline and sandy barrier erosion has taken place to the west of the entrance (refer figure 7). Detailed shoreline changes to the east and west of the entrance between December 2005 and March 2009 are documented via EPR application at figures 8 and 9. They show that most shoreline changes have occurred close to the artificial entrance, with most changes at other transects being within +/-6m.

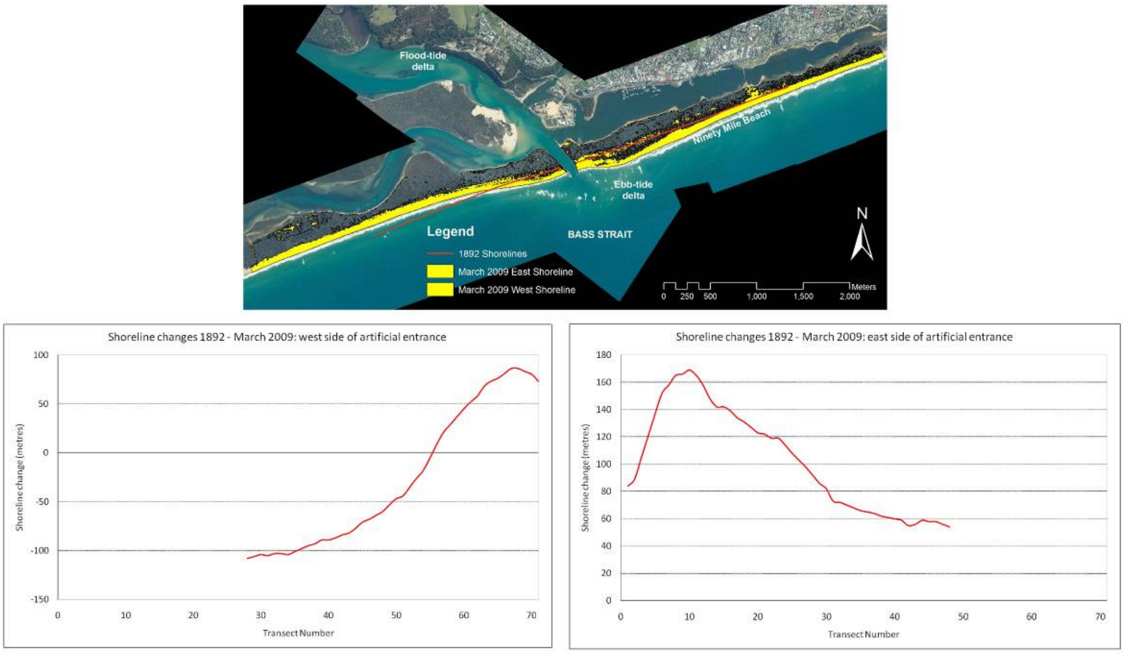

Figure 7. Survey area shoreline changes: 1892-2009

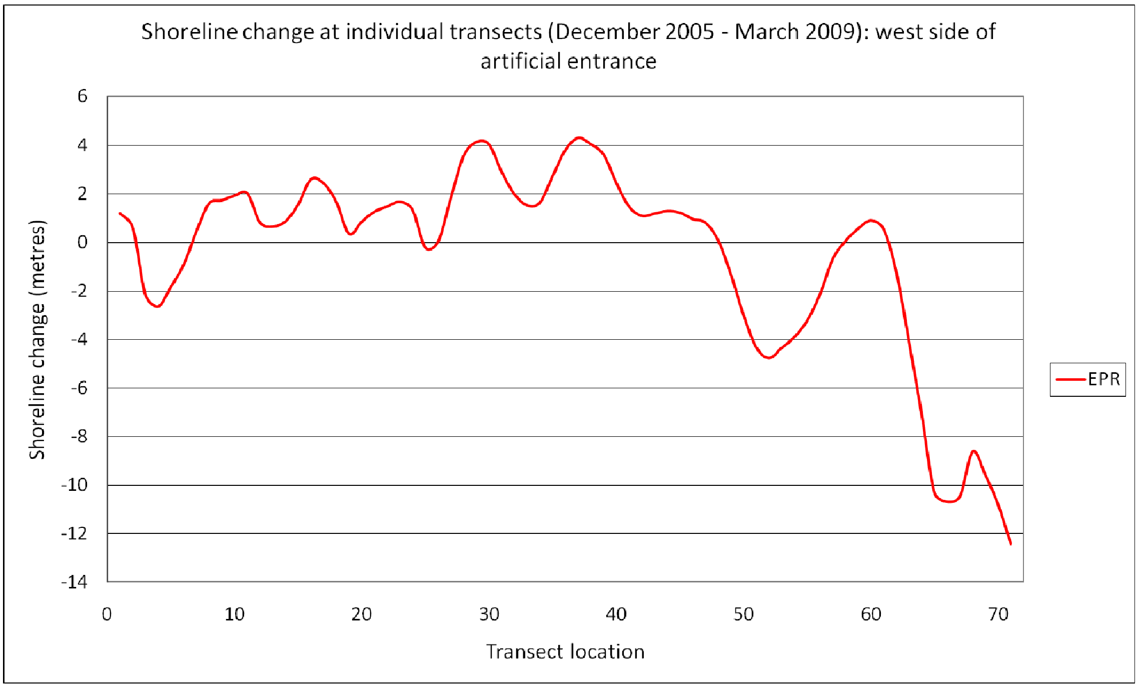

Figure 8. Survey area (west) shoreline changes: December 2005 to March 2009

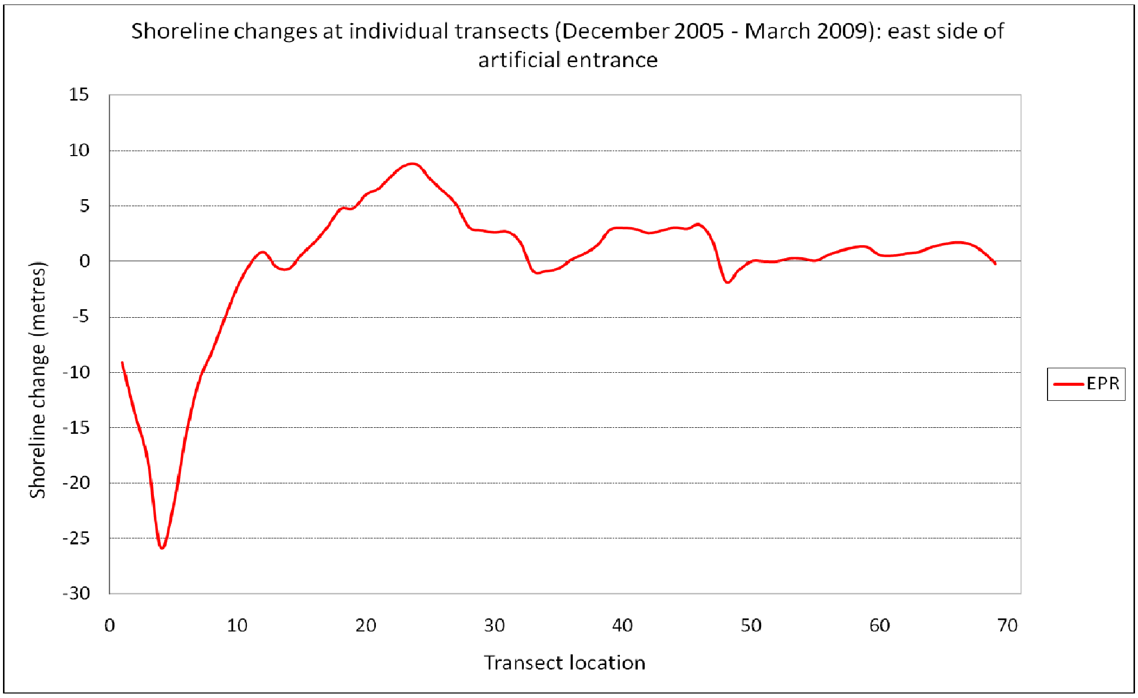

Figure 9. Survey area (east) shoreline changes: December 2005 to March 2009

DISCUSSION

Results show that there has been significant sandy barrier shoreline change to the east and west of the Gippsland Lakes artificial entrance over the period 1892-2009. The influence of the artificial entrance area (including the development of interconnected flood and ebb-tide delta morphological units since entrance commissioning in 1889) in acting as a barrier to longshore sand transport, has caused sandy barrier and shoreline changes for many kilometres to the east and west. The significant erosion to the west of the entrance, and the progradation to the east (refer figure 7), attests to the overall dominance of east-to-west net longshore drift along the Ninety Mile Beach in this sector of coast, driven by ubiquitous southeast 12-14 second swell wave trains from the southern Tasman Sea: the dominant beach-building wave, and determinant of the alignment of the Ninety Mile Beach.

Shoreline change results for the period 2005-2009 (refer figures 8-9) show that with the exception of shoreline areas immediately to the east and west of the artificial entrance, changes have been relatively minor. Installation of a sand transfer system (STS) by Gippsland Ports Authority in 2001, which pumps sand dredged from the flood-tide delta to an outfall site on the Ninety Mile Beach (some 1.1km to the east of the entrance) has had little effect in terms of re-nourishing down-drift barrier beaches to the west of the entrance, although it is likely that this system has contributed to progradation of the barrier beach to the east of the entrance. By pumping flood-tide delta sands to the dominant up-drift side of the entrance (the east), it has ensured that a proportion of the sands it discharges will almost certainly be transported back to the flood-tide delta. Clearly, any new sediment bypass system at the artificial entrance (as recommended for trials as a component of the LESMP, 2006) should be designed to pump bi-directionally to the east and west of the entrance, depending upon the dominant longshore drift pattern, and be of sufficient capacity to accommodate a reasonable proportion of littoral drift sand volumes, so its operation will effectively nourish down-drift beaches.

Results show that there is a marked seasonal variation in leaf index that must be taken into account when using time-series air photos to document land cover change. Williams and Randerson (1989) find that an understanding of the seasonal dynamics of the vegetation of coastal systems is important from a management perspective, since some forms of disturbance can most readily be observed only during certain seasons, and may correlate with the composition of specific plant communities. Seasonal variations in sandy barrier vegetation types may be related to the seasonal phenology of the species (Cordazzo and Seeliger, 1988). Seasonal growth patterns can affect the spatial pattern of dune vegetation species, the spatial relationship of one species to another, and hence local species associations and community types (Gibson and Looney, 1992). Local changes in the ground water regime have also been shown to alter the spatial and temporal relationship between dune species, and in addition, there can be associated seasonal differences in the soil fauna (van der Laan, 1979).

Results provided in this paper offer a baseline for future monitoring of sandy barrier evolution in the vicinity of the Gippsland Lakes artificial entrance during and after sediment bypassing trials described in the LESMP (2006). Future monitoring, if carried out on a regular basis over the coming years, may also detect sandy barrier response to predicted eastern Bass Strait wind and wave environment changes (e.g. see McInnes *et al.*, 2005a, 2005b, 2006) and Gippsland Lakes catchment change (e.g. see Brooke and Hennessy, 2005). Sandy barrier morphology response to predicted global sea level changes (refer IPCC, 2007; GCB, 2008; Cowell *et al.*, 2006; Davidson-Arnott, 2006) may also be monitored for over the longer-term. Regular high-resolution monitoring of coastal environmental indicators in Australia has been repeatedly called for (e.g. see Environment Australia, 1998). As shown in this paper, remote sensing of sandy barrier environments offers a set of tools with which semi-automated coastal environmental indicator monitoring can be effectively achieved.

CONCLUSIONS

Sandy barrier and shoreline changes along the Holocene sandy barrier, now known as Ninety Mile Beach, in the vicinity of the Gippsland Lakes artificial entrance have been significant since 1892. The changes documented by this study support the following statements:

- The net littoral drift on the coastal sector under study here is east-to-west;
- Interference caused by the artificial entrance to natural littoral drifting processes has caused sandy barrier progradation to occur east of the entrance, and sandy barrier erosion to the west of the entrance;
- The recently-installed sand transfer system, discharging east of the entrance, augments the contrast, as the system is not bi-directional;

- A seasonal cycle to sandy barrier vegetation coverage between 2005-2009 was detected; less in summer than in winter. This result could be further researched for possible detailed explanations pertaining to such change.

The results of this study offer baseline data which may be used for future monitoring and research purposes. They indicate the scope and utility of GIS deployment for the high-resolution semi-automated monitoring of sandy barrier coastal environments.

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